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Minimization of passenger takeoff and landing risk in offshore helicopter transportation: Models, approaches and analysis

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ABSTRACT

Offshore petroleum industry uses helicopters to transport the employees to and from installations. Takeoff and landing represent a substantial part of the flight risks for passengers. In this paper, we propose and analyze approaches to create a safe flight schedule to perform pickup of employees by several independent flights. Two scenarios are considered. Under the non-split scenario, exactly one visit is allowed to each installation. Under the split scenario, the pickup demand of an installation can be split between several flights. Interesting links between our problem and other problems of combinatorial optimization, e.g., parallel machine scheduling and bin-packing are established. We provide worst-case analysis of the performance of some of our algorithms and report the results of computational experiments conducted on randomly generated instances based on the real sets of installations in the oil fields on the Norwegian continental shelf. This paper is the first attempt to handle takeoff and landing risk in a flight schedule that consists of several flights and lays ground for the study on more advanced and practically relevant models.

1. Introduction

In offshore petroleum industry, employees are transported by helicopters to and from offshore installations in the Norwegian Sea and the North Sea areas. Travel by a helicopter is more comfortable and less harmful in terms of travel sickness and tiredness as compared to travel by ship with a considerably longer duration. However, helicopter transportation is perceived by many offshore employees to be a risky part of their work. They experience heaviness and weightlessness during takeoff and landings, heavy noise, strong vibrations, and even sometimes incidents or accidents. Vinnem et al. [1] claim that the hazards associated with helicopter transportation of personnel are among the main risks experienced by offshore employees.

Helicopter accidents are reported fairly frequently. European offshore helicopter data reveal that there have been 23 fatal and major injury accidents in the offshore oil industry from 1968 to 2000 [2]. A recent summary report from the Helicopter Safety Study 3 (HSS-3), undertaken by SINTEF Trondheim, indicates that among 28 OGP[1] offshore accidents from 2000 to 2005, 22 occurred during the takeoff or landing phase. Since the first version of this paper was written, three accidents have occurred in the North Sea, two in 2012 and one very recently, in August 2013; the latter accident claimed four lives.

Helicopter planning to offshore installations may be done by a helicopter operating company (as for Statoil) or by the oil company itself (as in Petrobras). Safety is always considered together with traditional measures while planning. But in all known publications on helicopter planning to offshore installations the problem is defined as a vehicle routing problem (VRP) with traditional cost or distance objectives. The vehicle routing problem is well-studied, and numerous computational techniques are available for its different variants, see for example [3–10] for the recent work.

Among the few published research papers on the helicopter routing to offshore installations, Moreno et al. [11] and Menezes et al. [12] seek to minimize the flight costs, the number of flights, and the total number of offshore landings in order to improve helicopter flight safety. Qian et al. [13] introduced a risk measure for passenger transportation by helicopter and defined a safe passenger helicopter transportation problem as a vehicle routing problem with pickups and deliveries with a risk objective in terms of the expected number of fatalities. Two types of accidents, i.e. takeoff and landing accidents and cruise accidents, are considered as possible during a flight. The problem is formulated as an integer linear program, which generates Hamiltonian solutions.

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[1] The International Association of Oil and Gas Producers.

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The term 'Hamiltonian' refers to the fact that each installation is visited exactly once for the combined pickup and delivery within a flight. Qian et al. [14] extend the previous work and consider a general routing policy, under which each installation is allowed to be visited twice if necessary, once for delivery and once for pickup. A tabu search heuristic was implemented for real-life instances based on data taken from the Norwegian Continental Shelf. A comprehensive study was conducted to gain insights into passenger transportation safety by comparing the solutions obtained from optimizing risk or cost objectives under different helicopter routing policies. In these two papers [13,14], the helicopter routing problem was defined as VRP, with risk objective which is partly distance dependent (in cruise risk part) and partly sequence dependent (in takeoff and landing risk part). One of the interesting findings of these two papers is that takeoff and landing risks are the major part of the transportation risk for passengers.

In this study we, while fully appreciating the importance of the traditional measures of the schedule quality, would like to focus an another important factor, the takeoff and landing risk. The fact that we want to create a schedule that minimizes such a risk does not mean that we want to dismiss flight schedules that perform well against traditional cost functions. The minimum risk flight schedules will complement those schedules that can be found by the vehicle routing techniques. Even if the minimum risk flight schedules might not appear to be the most cost-effective, we believe that having these schedules at hand will extend the number of options for the decision-maker to choose from. Focusing on minimizing risk allows us not to rely on the VRP techniques, but develop methods that are related to the problems of machine scheduling and bin packing.

As one of first attempts to handle the minimum risk scheduling for several flights, in our model we make several simplifying assumptions:

- the risk is measured as the total number of people exposed to takeoffs and landings in all flights;
- we focus on minimization of passenger takeoff and landing risk in helicopter transportation, provided that only pickup demands are considered.

In reality, measuring the total risk should additionally include the assessment of the cruise risk factors; however, the latter aspect again can be modeled by the VRP, and in this paper we only address the takeoff and landing risk, as the most substantial risk component which should be handled by a different approach.

Also in practice, a typical flight schedule performs both pickups and deliveries, e.g., changing the staff of a shift on a platform, totally or partly. The problem of minimizing the takeoff and landing risk with simultaneous pickups and deliveries for a single flight has been successfully handled by [14]. In the case of several flights, we are still not aware of a possible approach to tackling simultaneous pickup and deliveries by several flights, even uncapacitated. The model that allows pickup only (or, in the symmetric case, delivery only) is not totally irrelevant and can be useful in the case of removing staff from installations in the case of their conservation or emergency. Delivery only and pickup only take place in the case of transporting teams of visitors (inspectors, journalists, researchers, etc.) to and then from the installations.

We do not expect that our main model, currently being stripped off most difficulties that arise in practice, will lead to an immediate practical implementation. Still, we believe that it captures many features that distinguish this direction of research. We see this paper as a necessary stage which is aimed at (i) initiating research on safe helicopter transportation by several flights; (ii) establishing links between the safe helicopter transportation problems and traditional problems of combinatorial optimization, including bin-packing and scheduling problems on parallel machines; (iii) laying grounds for the study on more advanced, enhanced and practically relevant models.

From the point of view of the theory of Operational Research, we think that the established similarities and differences between our problems and the related problems of combinatorial optimization are especially attractive; in particular one of our models leads to a scheduling problem on parallel machines with the processing conditions that have not been studied before in full form.

In our models of safe helicopter pickup, two scenarios of transportation are considered: (i) the non-split scenario under which all people to be picked up from an offshore installation are collected by a single flight, and (ii) the split scenario under which multiple visits to installations are allowed, each flight collecting a part of people to be picked up. For each scenario, we present several algorithms accompanied by worst-case analysis of their performance and/or computational experiments.

The remainder of this paper is organized as follows. In Section 2, the connections between the safe helicopter transportation problem and scheduling problems on parallel machines are presented and the related work is reviewed. The non-split scenario is studied in Section 3. The split scenario is considered in Section 4, followed by conclusions in Section 5.

2. Problem formulation and links with machine scheduling and bin-packing

In all models considered in this paper, a *flight* is a route of a helicopter that starts at an onshore heliport with no passengers on board, visits the selected offshore installations exactly once in a certain order and ends at the same heliport. In principle, during a visit both pickup and deliveries may take place, however in this paper we focus on the pickup operations only. See Qian et al. [14] for a study of the pickup and delivery operations in a single flight.

Computational results in [14] show that for the considered instances the most essential component of the risk associated with offshore transportation is the takeoff and landing risk. Let

- f_{TL} denote the probability of an accident during a combined takeoff/landing operation;
- z denote the probability of a fatal outcome for an individual involved in a takeoff/landing accident;
- PTL denote the total number of people exposed to takeoffs and landings.

For example in [13] the frequency f_{TL} of takeoff and landing accidents is 0.65 per one million of takeoff and landing pairs, while the probability z is assumed to be equal to 1. Thus, the takeoff and landing risk can be measured as the product $PTL \cdot f_{\text{TL}} \cdot z$. The probabilities f_{TL} and z can be seen as constants that do not depend on the routing decisions. Thus, in order to minimize the takeoff and landing risk, we need to minimize the variable component of the risk function, i.e., the PTL. In turn, the problem of minimizing the PTL is closely associated with certain scheduling and sequencing problems, as explained below.

Assume that a helicopter of capacity Q is available, i.e., no more than Q passengers can be present on board in any stage of a flight. Let $N = \{1, 2, \ldots, n\}$ be a set of installations to be visited, and an installation $j \in N$ is associated with a pickup demand p_j. Throughout this paper for a non-empty subset $N' \subseteq N$ of installations we denote

$$p(N') = \sum_{j \in N'} p_j,$$

i.e., $p(N)$ denotes the total pick-up demand from all installations.